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Lincoln Cathedral

A PAPER ON THE EARLY HISTORY
AND THE VARIOUS DISASTERS AND
RESTORATIONS IN THE PAST, AND
THE PRESENT SPECIAL REPAIRS

ROBT. S. GODFREY

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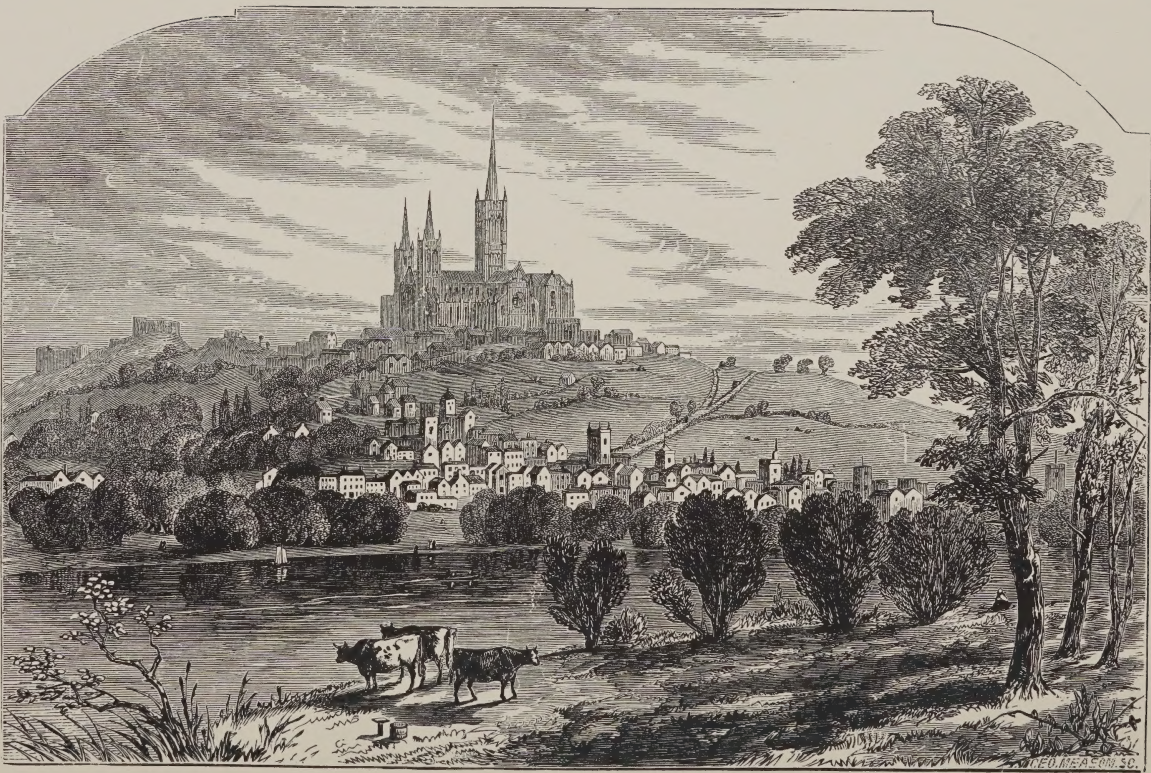
GEO. MEASOM. SC.

LINCOLN CATHEDRAL.

As it appeared before the spires were taken down in 1808.

(Old woodcut in the possession of the Lincs. Publishing Co., Ltd.)

LINCOLN CATHEDRAL

A Paper on the Early History and the various Disasters and Restorations in the past, and the present Special Repairs

Given to the Rotarians, Lincoln Branch,
November 16th, 1925,
By Robt. S. Godfrey, Clerk of the Works.

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The Deanery,
Lincoln.
January, 1926

FOREWORD

I HAVE been asked by Mr. R. S. Godfrey, our valued Clerk of Works, to write a Foreword to his address on the methods of repairing Lincoln Cathedral.

These have been adopted by our Cathedral Architect, Sir Charles Nicholson, Bart., in concert with Sir Francis Fox, whose name is so closely associated with the saving of Winchester.

Mr. Godfrey's address speaks for itself; but he cannot say what I can say, *i.e.*, that we all owe to his care, watchfulness, ingenuity, and devotion a very great debt. The fund we have already raised and almost spent, could not without his care and economy, have done so much for us.

We still need a large sum to enable us to finish. Everyone who buys this little book will constitute a welcome mite; everyone who, after reading it, sends us more will assist Mr. Godfrey's desire to help on to a successful conclusion one of the best engineering efforts of this century, which is, to repair a Cathedral without marring its ancient beauty.

T. C. Fry.

LINCOLN CATHEDRAL

ITS RESTORATIONS & SPECIAL REPAIRS

Mr. President, Chairman, Brother Rotarians

BEFORE dealing with the Special Repairs, as the question has been so often asked during the past four years, " Why has the Cathedral been allowed to get into such a state of repair, so as to demand all this money to be spent upon it ? " I propose, in the short time at my disposal, to try and tell you of the various disasters to the Cathedral ; also of the various repairs of which we have record that have been carried out from time to time ; and this I hope will answer the above question.

But to answer this satisfactorily, it will be necessary for me to speak at some length on the history of the building of the Cathedral. At the same time I do not propose to deal with the history of the Cathedral as a whole ; this would take up too much of the allotted time ; I shall therefore confine myself to those portions which are being treated under the present Special Repairs scheme.

During the paper, I shall refer to the various drawings that are hung up in the room ; and to the photographs, which I would like you to inspect and pass round.

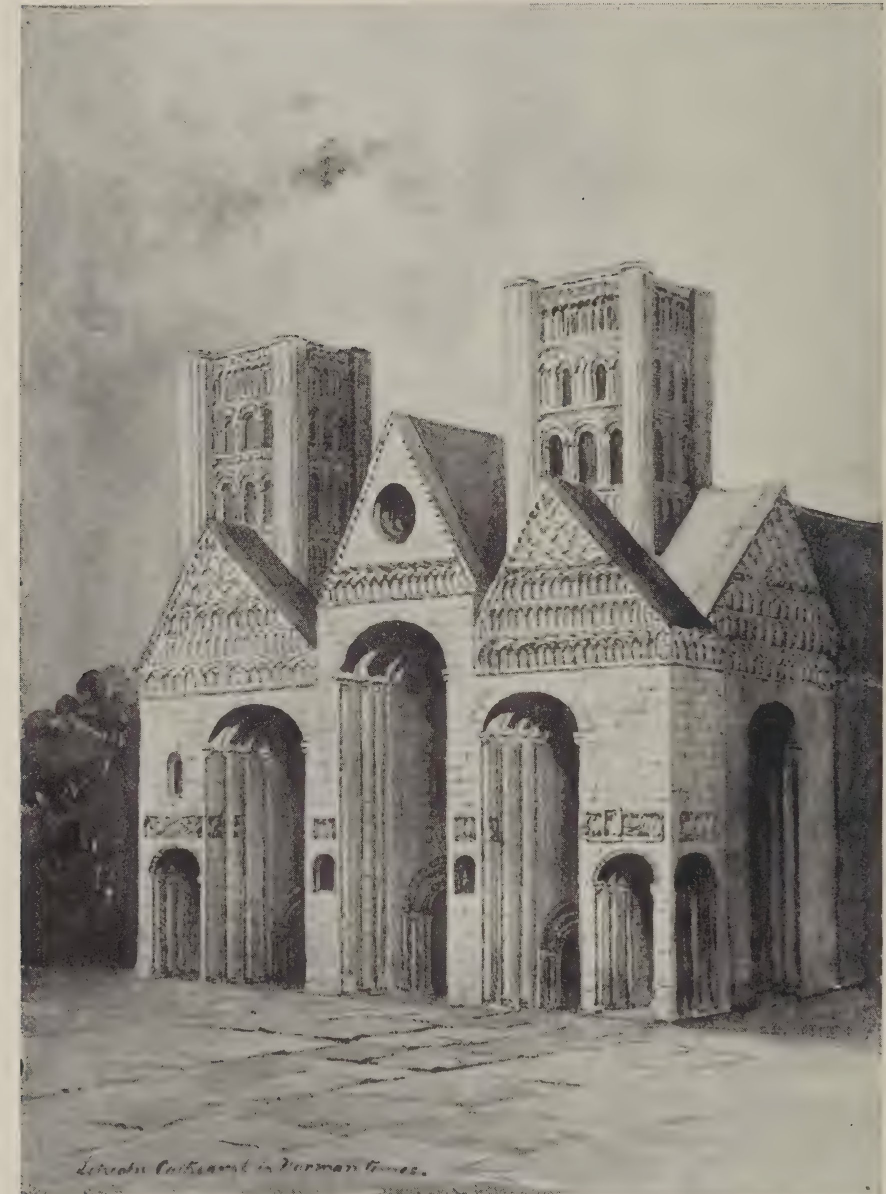
Leaving out all historical facts prior to the building of the earliest portion of the Cathedral, we will for a few moments look back to the first Norman Bishop, Remigius ; probably a few words about this Prelate may not be out of order. Remigius bears too important a part in this history not to deserve some special mention. There is little known of him, personally at least, before his arrival in England. A discovery made in comparatively modern times appears to establish his claim to be of the blood of the great house of Deincourt, who were allied to the Conqueror. If this be so, then one can more readily believe what is recorded in history, of how he assisted the Conqueror with his invasion of England, by contributing a ship and twenty armed men towards this expedition. This adventure having succeeded, the Conqueror began to reward his followers; and the very first Mitre he bestowed was given to Remigius.

Wulfing, Bishop of Dorchester, died soon after the Conquest, and the Monk of Fescamp took his place. Of the proceedings of Remigius at Dorchester we have little record; the most material fact known is that he proposed to build a Cathedral there, and made preparations accordingly. Dorchester however was not to have the benefit of his labours in this direction; the See was translated almost to the other extremity of the Diocese, to the then rich and populous City of Lincoln. It may be of interest to you to know that the Charter confirming this, and granted by William the Conqueror, is still preserved in the Cathedral Library, and can be seen by visitors.

The generally acknowledged date of "The King's Licence to remove the See from Dorchester to Lincoln" is 1075 Remigius appears to have had great taste for Architecture, and an energy and activity which continually urged him to some useful object.

As regards the time at which the building was commenced, several dates have been suggested ranging between 1075 and 1090. No doubt several years would be spent in the purchase of ground, in preparing the site, and in the accumulation of the vast stock of materials which would be necessary before any part of the work could be begun.

In what way Remigius secured a site for his Cathedral, is but imperfectly known. The South East quarter of the original Roman City was cleared for it, as also the South West quarter by the Castle.


Lincoln Cathedral in Norman times.

LINCOLN CATHEDRAL IN NORMAN TIMES.

If, as is generally believed, the Church of Remigius in its ground plan, was identical with that of St. Hugh afterwards erected, the East end of which reached a little beyond the present Altar Screen, he must have pulled down the City wall, and enclosed apparently the ditch beyond it, as the wall beyond question ran through the East Transept.

That the structure was considered a magnificent one in those days (see plate opposite) we have the testimony of Henry of Huntingdon and William of Malmesbury, both of whom saw it before its ruin by fire in 1124: the former of these historians was an Archdeacon of the Church, and lies buried in the South angle of the lesser Transept, though no memorial remains.

Mr. Essex, the Consulting Architect to the Dean and Chapter in the eighteenth century, and one of the first revivers of a study of architecture on sound principles, was much employed on the repairs of our Cathedral, and gave no small attention to its history and more recondite features. He investigated closely the traces of this early Church of Remigius; and was of opinion, that in point of extent (of ground plan at least) it corresponded to the existing fabric, excepting at the East end, where it terminated with a semi-circular sweep near the present Altar.

Of the Towers (which were arranged as at present) only the Western ones remain, and those much heightened in times subsequent to Remigius. The West Front or Screen which they surmount still contains, as its centre portion, the original West Front of Remigius's Church, which is easily distinguishable from the additions both to its height and breadth, by the semi-circular form of its arches, as well as by the ruder masonry and the smaller masses of stone employed.

Adverting to the date when the actual building commenced, we have no definite record, but we do know that the Church was ready for consecration in 1092. This may merely imply the completion of the Choir, so as to admit of the celebration of Divine Service.

To what extent even the Choir might in this instance be left unfinished may be a matter of speculation, as we find that the aged founder, feeling his strength failing, urgently desired to see his great work so far consummated before his death, and to that end invited all the Prelates of the Realm to assist at the ceremony of consecration ; but he was not allowed to witness the solemn dedication : he died on the very eve of the day appointed : Ascension Day, May 6th, 1092.

These few notes of the erection of the earliest portion of the Cathedral and the first Bishop of Lincoln may to some appear to be needlessly prolonged : others, it is hoped, will regard them as due to one of the remarkable men of his own age, little remembered in ours. Many of the mediæval glories of Lincoln have long passed away : the pomp of the Courts and Parliaments are alike silent ; but the Towers of Remigius still stand, land marks from afar-off, even for foreign pilgrims in search of the beautiful.

Robert Bloet was the second Bishop, and on his death, which took place 1123, Alexander the Magnificent succeeded.

A fire occurred in 1124, the extent of which may be variously interpreted from the early writers ; but we learn that the injury was substantially repaired by this Bishop, who further vaulted the roofs with stone, a novelty then greatly admired, for the prevention of future like accidents. The Centre Aisle had been originally ceiled with wood only, as seen at Peterborough ; side aisles were not uncommonly vaulted with stone, although it is doubtful whether such was the case at Lincoln.

The next calamity to befall the Cathedral, was the great earthquake, which occurred 1185. This earthquake was of such magnitude, that it practically destroyed the whole of the Cathedral ; the only portion left standing were the two Norman Towers and the Norman West Front.

In the following year, Hugh of Avalon, near Grenoble commonly known as St. Hugh, (who may be considered as the second founder of the Cathedral), was consecrated Bishop.

Hugh was an energetic man, ascetic and self denying, with a strong will, and he set an example of industry and zeal, by labouring with his own hands. He began by planning out a larger Church with double Transepts, working at the East end as well as at two other points at the same time.

Much has been written of the great and surpassing beauty of his work. It is certainly most picturesque and graceful; but at the same time it is more remarkable for lightness than for strength, as was shown by the fall of the Centre Tower 1244-5, which greatly damaged the Church.

Bishop Hugh died in 1200; his successors were William de Blois 1204, Hugh de Wells 1209, and Robert Grostete 1235. It was during this period that the present nave was built, and the Centre Tower repaired to its original height, probably to the first stage immediately above the height of the present roofs.

The next stage added to the Tower is attributed to Bishop Dalderby about 1306: the final stage as we see it to-day, less the Parapet; this Parapet was added to the designs of Mr. Essex, the Consulting Architect at that time, in the year 1775, at a cost of £1,967: including the four pinnacles.

Between 1436-39 a spire of timber and lead was added to the Centre Tower, reaching to a height of some 500 feet above ground level, 229 feet above the present four pinnacles. This spire was blown down during a heavy gale in January 1547, doing very serious damage to the Church.

Two similar spires were added to the Western Towers at the same date. These reached to a height of 281 feet, or 74 feet above the present pinnacles.

All three spires are attributed to Bishop Alnwick.

This is as far as I intend to carry the history of the building of the Cathedral, as it covers all those parts of the building, with which we are concerned in the Special Repairs now being carried out.

I will again remind you of the various disasters that have occurred to the Cathedral.

In 1124 the Cathedral was destroyed by fire.

In 1185 the Cathedral was destroyed by an earthquake.

In 1244-5 the Great Tower fell down, and in

1547 the Spire of the Centre Tower was blown down during a severe gale.

Following each of these respective dates, the Church has either been repaired or re-built, and as you will all understand, when portions of buildings of such magnitude collapse and fall on to the surrounding portions, a good deal of dislocation, one way or another, is naturally caused to those adjoining portions which are not carried along with the fall. Let me add that, during the past 800 years, the Deans and Chapters have carried out schemes of repairs and additions, with a view to strengthen and make good the various breaches, but in no single instance have any of these repairs or additions to the building, meant of course to increase stability, been entirely successful. They may have steadied movement for a time, but in some instances, especially in the additions, they have actually increased rapidity of movement.

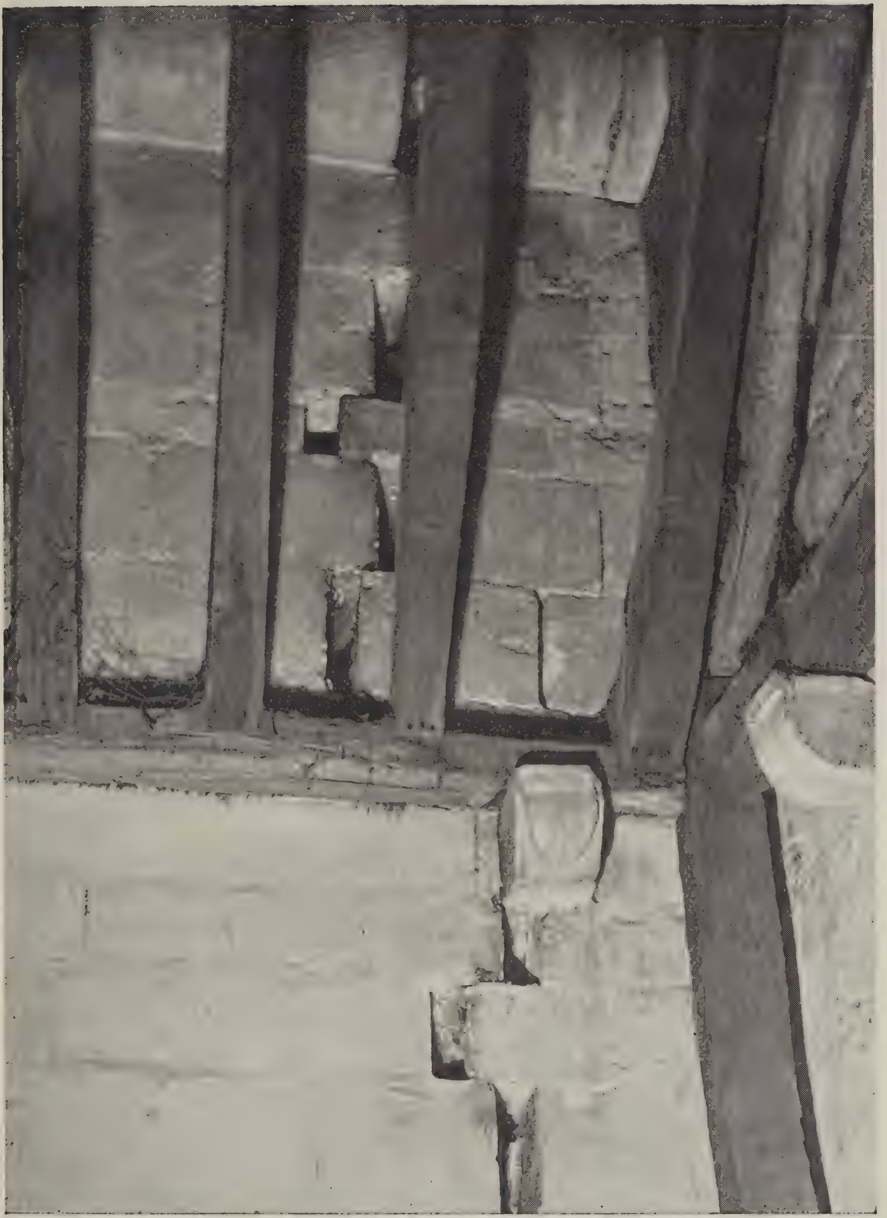
The early Norman Arches have had early English relieving arches built under them ; but, as the supports to these were not bonded into the earlier masonry, nor were of sufficient strength to sustain the enormous weight above them, they in turn caused further spreading.

As you will observe, notwithstanding all these precautions, the Towers continued to settle, and the cracks which were in the old work continued to grow larger and to spread in different directions.

These fissures in the masonry seemed formidable enough to justify the anxiety of the Chapter of a later period ; in fact they were so much increased (see plate opposite), that, the Towers themselves were thought to be in danger of falling. As a preventative, the building up of the two main arches under each of these two Western Towers was advised and carried out under the direction of Mr. Gibbs, the Consulting Architect of that period, 1726.

Mr. Gibbs also advised the taking down of the lead-covered spires of the two Towers ; but as the Citizens were very antagonistic (the attempt culminated in a riot), it was decided to leave them until a more convenient time. The demolition of the spires took place in 1808, as far as one can trace, without any opposition.

Even with this lessened weight, the movement still carried on ; for in 1820 heavy iron cramps were applied by the advice of an eminent Architect, to prevent further mischief by the spread of the fissures in the Towers. These bars are an inch thick,



N.W. ANGLE OF N.W. TOWER
(145 feet above the floor).

and four inches broad, the inside ones being carried through the wall at both ends, and through a corresponding bar outside, and screwed to it by a powerful nut. Five of these hoops, both inside and outside, are attached at proper distances, between the roof of the Church and the top of the Towers. According to a record that I have in my possession, about six tons of iron are thus used on each of the West Towers.

It may be of interest to you to know, that we intend to take off these iron bands as the repair work proceeds. Two of these at the highest point of the Tower are already taken off ; and on one the Smith's name and date is deeply stamped or cut in. The date coincides with that just given, 1820. Several of these iron bands are broken in two ; in some cases there is a distance of two inches between the broken ends which clearly shows spreading of masonry. In other cases, the bolt that carries through the wall has broken immediately behind the nut ; some of the nuts have fallen to the roof below ; others, that are rusted in, have stayed in their position, thus giving a false impression of security. In addition to these iron bands, some hundreds of iron wedges have been used to level up the courses of the masonry that had dropped, owing to the spreading of the Tower walls. The destruction of wrought iron to masonry is almost incalculable. Wrought iron is laminated, and, when the corrosion takes place, these laminations gradually open, and by this slow expansion the whole mass of masonry is either lifted or broken off. In some cases, hundreds of tons of masonry are being lifted or forced from their original position.

In 1875, the two Western and Centre Towers and other parts of the Cathedral were again reported to be in a serious state of disrepair. It was estimated by the then Consulting Architect, Mr. Pearson, that a sum of £77,000 would be required to carry out the repairs.

Of that sum only £33,000 was raised, and spent on certain parts of the Cathedral. Those parts that were untouched have, as you may expect, gone from bad to worse during these last fifty years.

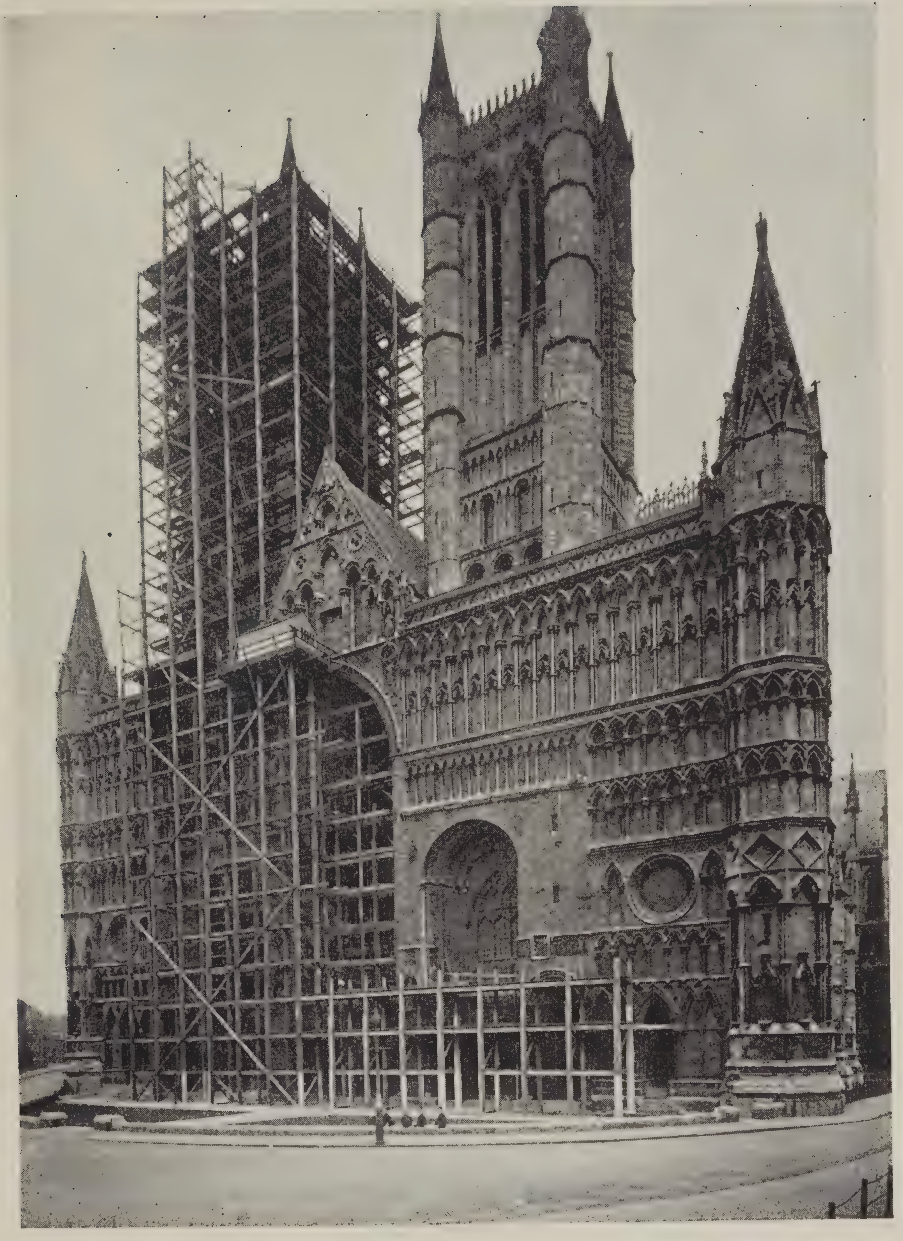
In 1876-79, and in 1884, a great deal of repair was carried out in the South West Tower, and on some portion of the West Front. Unfortunately for the present Dean and Chapter, the repairs carried out at that time were practically all face work. It was certainly good work ; but, as the present method of making good the core of the walls was not then known, certain sections of the walls of the South West Tower are again splitting, and there are cracks to-day from 1 inch to 6 inches wide, running practically the full width from the South West corner of the West Front to the South West angle of the North West Tower. These cracks prior to the present repairs, carried right across the North West Tower to the extreme North end of the West Front. One crack on the West face of the North West Tower at 90 feet up was 12 inches wide. This is now made good.

The South West Tower still urgently requires attention, as the tell-tales which are constantly replaced break within a few weeks after the fixing—a sure sign of continued movement.

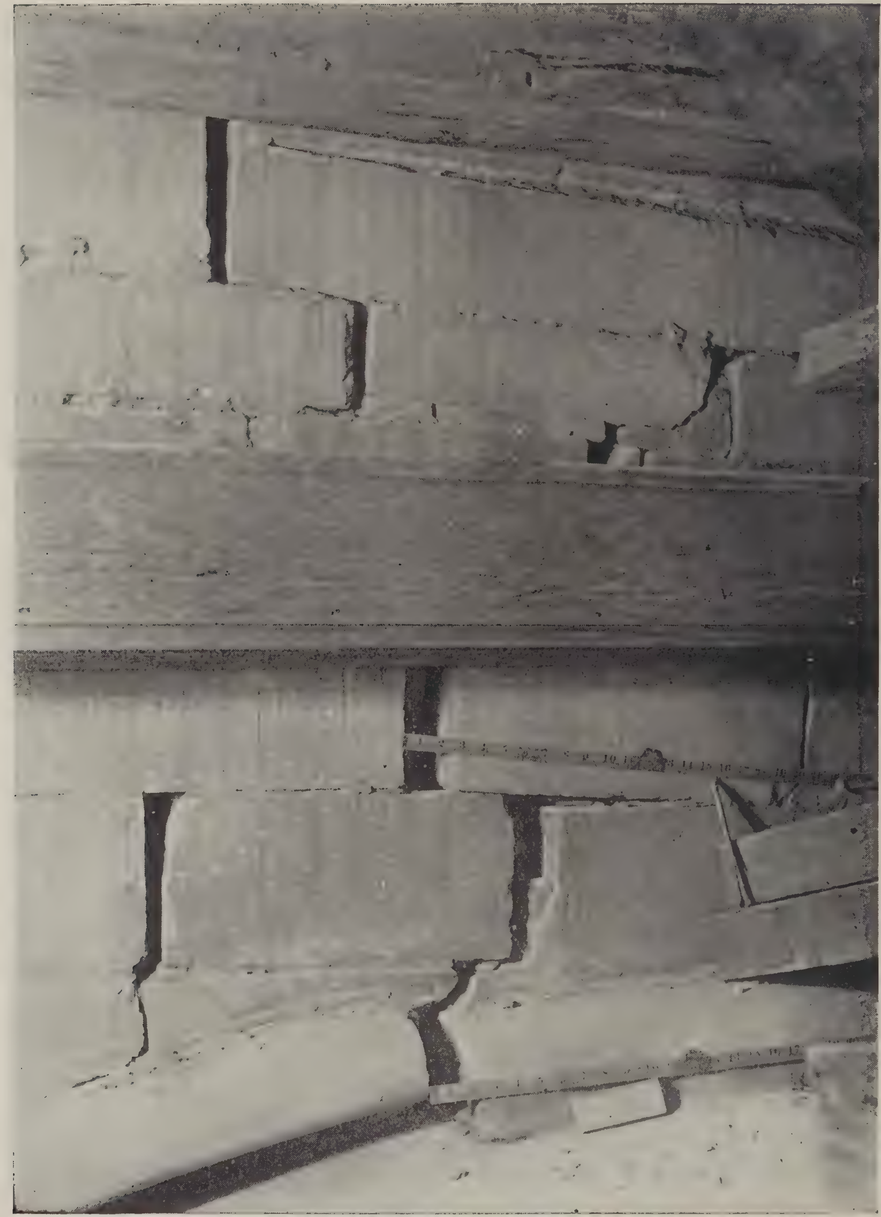
In 1896, the cracks in the walls of the North West Tower continued to open and spread in different directions ; and it was urgently necessary that something should be done, and done quickly, to prevent the collapse of the Tower. The Authorities at that time adopted the method of fixing strong iron bars through the walls at various levels, and on the most vital parts, running from East to West and North to South. This was a serious undertaking. To cut holes through masonry (in some cases 14 to 16 feet thick, and seriously dislocated) and that too without any dangerous slip was no mean achievement. Our present Master Mason, Mr. H. J. Davis, was on this work ; he tells me that, time after time, when they had nearly cut through the walls, the loose rubble would fall, and they had to begin all over again.

There is no doubt that the iron bars steadied the movement for a time ; but the whole of the masonry was so completely dislocated that the movement still carried on.

In 1921 the arches in the Bellchamber opened so widely that the arch-stones had to be strutted to prevent them falling out. Further the ribs of the vaulting of the North West Vestibule had dropped to such an extent, that instead of being concave they



VIEW OF WEST FRONT, WITH SCAFFOLDING.



TOP SIDE OF LANTERN IN CENTRE TOWER
(125 feet above floor).

were convex, and they were even threatening to fall to the ground.

Leaving the West Front, let us for a few minutes turn to the Centre Tower and its Transepts.

Here you will find the Authorities have, from time to time been engaged on the strengthening of the Centre Tower.

Behind the Arcading in the Lantern very strong relieving arches have been built in on each side, and additional columns inserted. This is so skilfully carried out, that, unless one were familiar with it, one would believe it to be the original design.

The Centre Tower, the Crowning Glory of the Cathedral, is most wonderfully light in construction. Unfortunately it has proved to be too light to be of sufficient strength to withstand the ravages of time. The Tower is constructed with what one may term a double wall, with passages running round each of the four sides. At certain heights these two walls are coupled together with strong bonding stones, and for a few feet upwards the two walls are coupled together with masonry; then again comes the two independent walls, and so on to the top of the Tower.

Owing to the continued spreading of the cracks in the walls to-day there is not to be found a single bonding stone intact. Each one, and they are many in number, shows fractures from $\frac{1}{8}$ to 2 inches wide.

The Tower walls are split in almost every possible direction, both vertical, horizontal, and longitudinal with the wall faces.

In 1924, the two sub-arches which are seen immediately above the vaulting of the Lantern, owing to the four main lower arches spreading, had collapsed to such an extent, that the weight of the masonry above was actually bearing on the vaulting of the Lantern; and as this is only of very light construction, only in fact intended to carry its own weight, it was showing serious fractures (see plate opposite).

All this dislocation has now been made good and completed to the Clock Chamber floor, 125 feet above ground level.

It is quite possible that the disintegration in the Centre Tower was caused, in the first place, by the fall of the Spire in 1547.

This also severely racked the North and South Transepts, causing the walls to buckle outwards ; this in turn has allowed the vaulting slightly to flatten, splitting and flaking the stones of the arch ribs.

The bad state of the Transept was pointed out by Mr. Essex in his survey in 1761, where he says " The roof over the North end of the great Cross is very bad ; here the rafters have run from the perpendicular, and, by pressing hard against the gable end, have forced that out of perpendicular likewise." A little further on, in his notice of the vaults, he points out that in this Transept the vault has the greater part of the weight of the leaning rafters to support, which has pressed the ribs in such a manner as to bend them very much ; this may be attended by bad consequences, by breaking the vault and throwing down the gable end of the Aisle unless it is repaired in time.

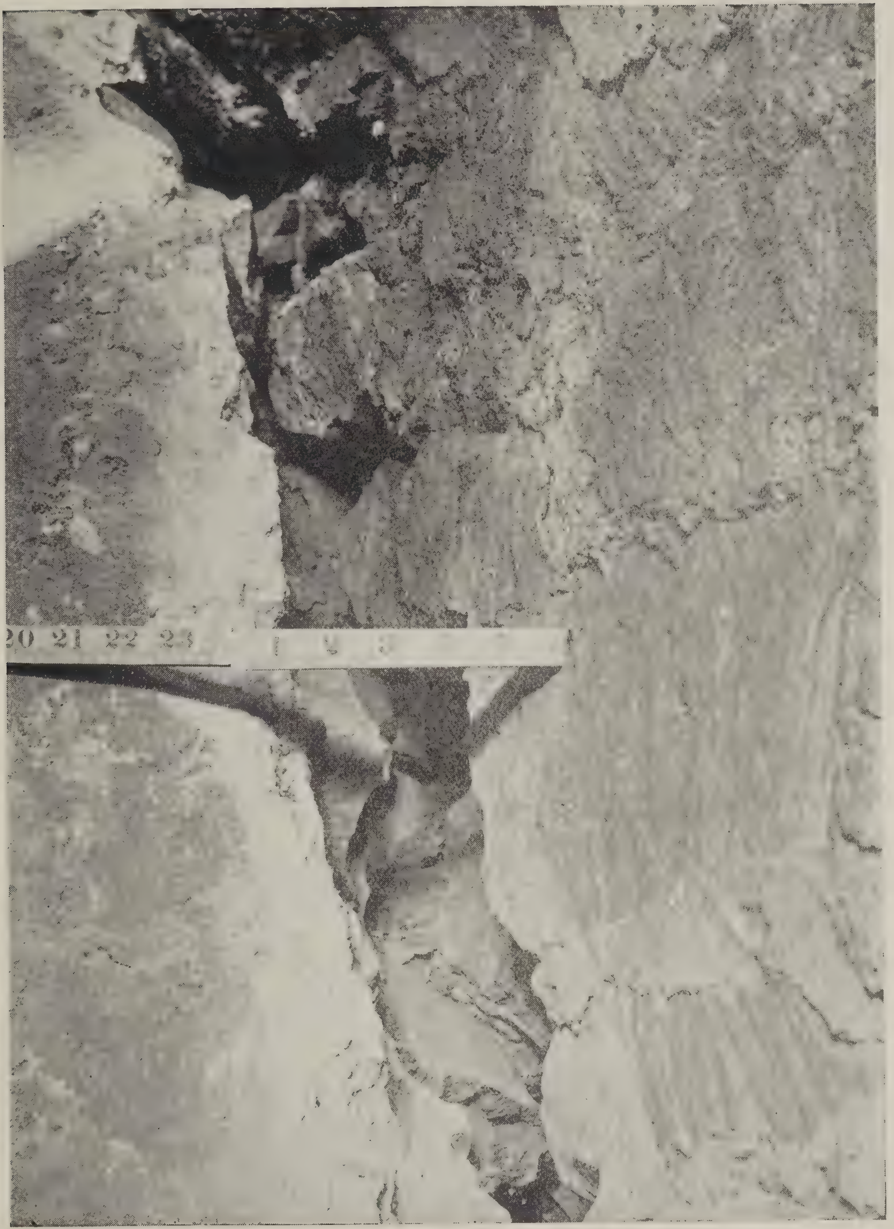
Mr. Essex accompanied his report with a working plan of " The Roof as it is," and another of " The Roof as it should be."

For some reason or other it was left in this state for several years, when Mr. Betham, the Clericus Fabricæ, had it promptly removed.

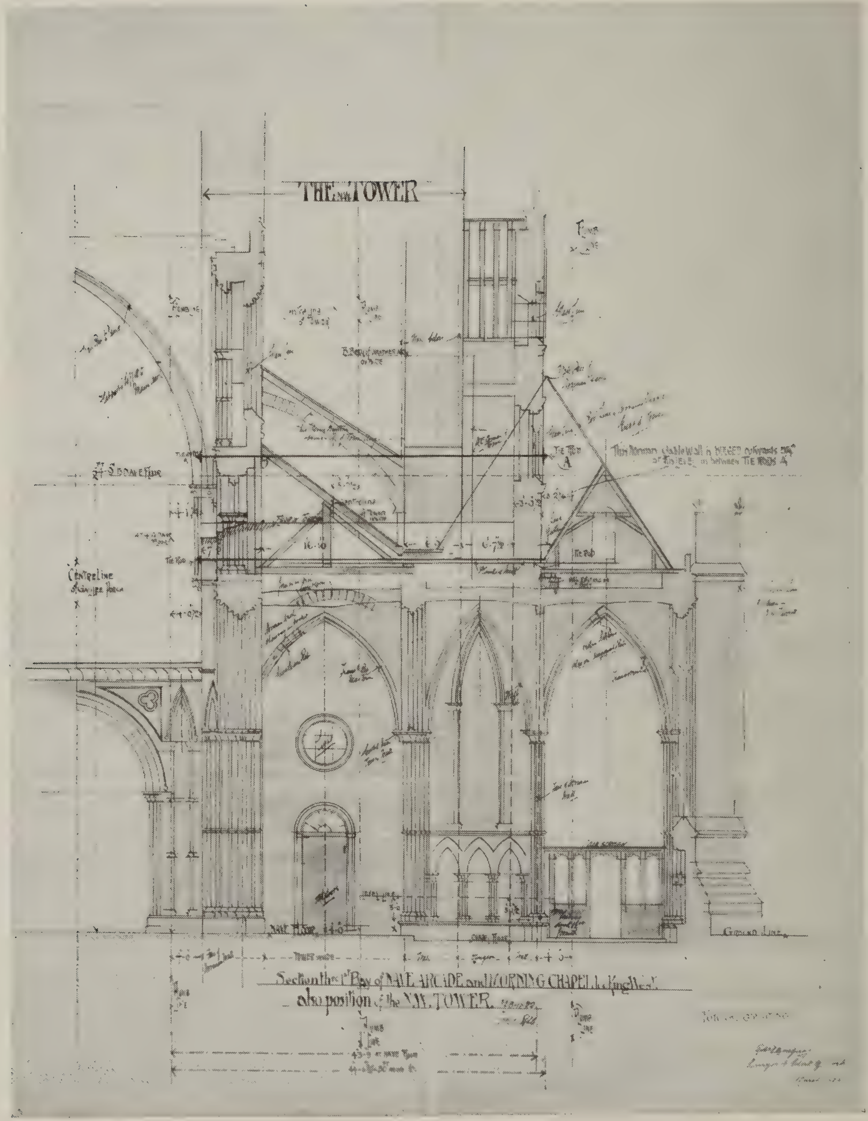
Owing to the Transept walls buckling, the vaulting had flattened to such an extent, as to show cavities from 4 to 8 inches in width between the vaulting and the main walls, up and down each cell, to the full length of the Transept. These cavities (see plate opposite) were not located, as a great many others were ; they were only revealed as the present repairs proceeded, owing to their being full of accumulated dust and debris.

The weight of the vaulting in each of these two Transepts is over 300 tons ; and the approximate weight of the Centre Tower is 13,237 tons. The total area of the four main piers at the base is 361 square feet. Assuming these bases to be carrying the total superimposed weight, it works out at 36 2-3 tons per square foot.

Adverting to the various abutments that have been made, I would like you to turn to Plan No. 1 showing the sectional elevation of the North West Tower from the East, and look to the right-hand side. There you will see an early English wall, covered with blank tracery ; this is carried to a height of 45 feet above



SOUTH-WEST TRANSEPT VAULTING



THE N.W. TOWER
Tie Rod A
Centre Line
16-10
6-2
6-7½
Ground Line
Section thro' 1st Bay of NAVE ARCADE and MORNING CHAPEL looking West
also position of the N.W. TOWER

PLAN No. 1.

Sectional Elevation of N.W. Tower.

ground level ; it is 17 feet wide from North to South, and 5 feet thick from East to West, at 4 feet above ground level. The masonry from this height down to the ground level gradually increases to 6 feet 6 inches thick. Previous to the present repairs this wall has always been termed an early English Screen. It is a Screen in one sense, because it screens off the early Norman work ; but it was not built for this purpose ; it was built as a buttress, and for the sole purpose of assisting to hold up the Norman Tower which was very much disintegrated on this East side owing to the earthquake. Another interesting fact about this section, is this, that the entrance to the early Norman staircase which led to the top of the Tower was behind this so-called Screen. Now if you will again look at No. 1 Plan, and blot out from your mind all the additions since the Norman times, you will be able to realize how weak this East side was.

The South East corner of the North West Tower was supported by a stone pier, totally inadequate to carry the weight of the upper part of the Tower ; this also applies to the North East corner of the South West Tower. The old builders cased the pillars and arches that supported the inner angles of the West Towers, and also constructed the flat arch between the two Towers to prevent them falling inwards.

It is on record, that the walls on the East side at this height were only 13 inches thick.

The South wall inside the North West Vestibule was thinly veneered over by Treasurer Welbourn in the fourteenth century, for several reasons. One reason was to hide the cracks in the Norman Tower wall and give additional strength ; another was to give support to the new vaulting that was added at this date in both North and South Vestibules. This veneering had no bonding to the old work. In some cases there were gaps of several inches in width. This is now cramped up with Delta Bronze Cramps and grouted up, making it equal to a perfectly solid wall.

The approximate weight of the North West Tower is 8,500 tons, equal to 19 tons per square foot on the foundations.

Now we come to the facts which necessitated the present repairs. In July, 1921, I was carefully examining the North

West Tower, and found that considerable movement had taken place since my previous examination. I immediately started to have tell-tales fixed over every single crack that could be reached with ladders, and every teller was indited with drawings on paper. After this was completed, and some time had elapsed, they were all examined and checked, and those broken replaced. These were eventually again examined, and finally we found out where the greatest movement was taking place. This was at some 90 feet above ground level. The tell-tales fixed at this height one day were found to be broken in two the next. On one occasion, on October 29th, after a gale of wind, we found tell-tales had opened 1–16 of an inch. I immediately sent in a report to the Dean and Chapter.

Owing to the serious condition of the building, the Dean and Chapter very wisely called in Sir Francis Fox, the great Engineer who saved Winchester and other notable buildings from collapse, in joint consultation with Sir Charles Nicholson, the Consulting Architect to the Cathedral. After a thorough examination they came to the conclusion that it was only by grouting under pressure, that the Cathedral could be saved.

Steps were immediately taken to get the necessary plant to commence operations.

It may be of interest to you to know that the Grouting Machine was invented by Mr. James Greathead about 1888 for use in construction of deep tunnels and the Electric Tube Railways of London, and has been used with great success for the securing of notable Road and Railway Bridges, Winchester Cathedral and many other Historic buildings right down to the present time.

Owing to the extensive amount of grouting that would be required at Lincoln, and the thickness of the walls that we had to penetrate, in some cases 20 feet thick, it was decided to purchase a Motor-driven Air Compressor. This was delivered and grouting commenced on March 9th, 1922. We very soon found out, that owing to the looseness of the rubble core, some other method less costly and also less dangerous, other than the ordinary hammer and chisel must be applied to enable us to get the grout right into the heart of the walls.

To this end Jackhammers driven by compressed air were purchased. These tools have proved to be most effective from every point of view. It is nothing unusual to drill a hole in the walls to a depth of 12 feet in one hour; thus two men can do in one hour, what would take two men five to six days to do with the ordinary hammer and chisel method. This was not the only point we had to consider. The condition of the masonry was almost at the point of collapse, and would not stand the heavy blows of the hammer; whereas the Jackhammer, although it makes a terrific noise in working, gives a percussion blow, with very little jar to the building. By these Jackhammers we have drilled into the masonry of the North West Tower up to October 28th inclusive 11,774 holes, approximately 5¾ miles in length, the number of holes in the Centre Tower and Transepts being 10,623, approximately 3½ miles, a total of 9¼ miles.

An accurate written record is issued week by week, and in many instances drawings are made showing the exact position where every hole has been drilled and the line it takes, where every cramp has been inserted, and where every gallon of grout has been forced in.

By this method of grouting you are able to repair the most ancient and beautiful buildings without in the least degree defacing their antiquity. At the same time you practically re-build the Church, making it some hundreds of times stronger than it was when first built, without so much as moving a stone.

It may interest you to know, that the improved method of grouting, and the drilling of the walls by the Jackhammers, which originated at Lincoln, has been adopted and is being carried out at Durham Castle, St. Paul's Cathedral, and elsewhere.

All this has aroused a world-wide interest. Notable Engineers and Architects from all parts of the world have been and inspected it, and have written expressing their full approval of what we are doing.

Before proceeding further, I would like to say a few words about grouting. As you know, there was a great deal of controversy for and against grouting while St. Paul's was appealing for funds in the early part of this year.

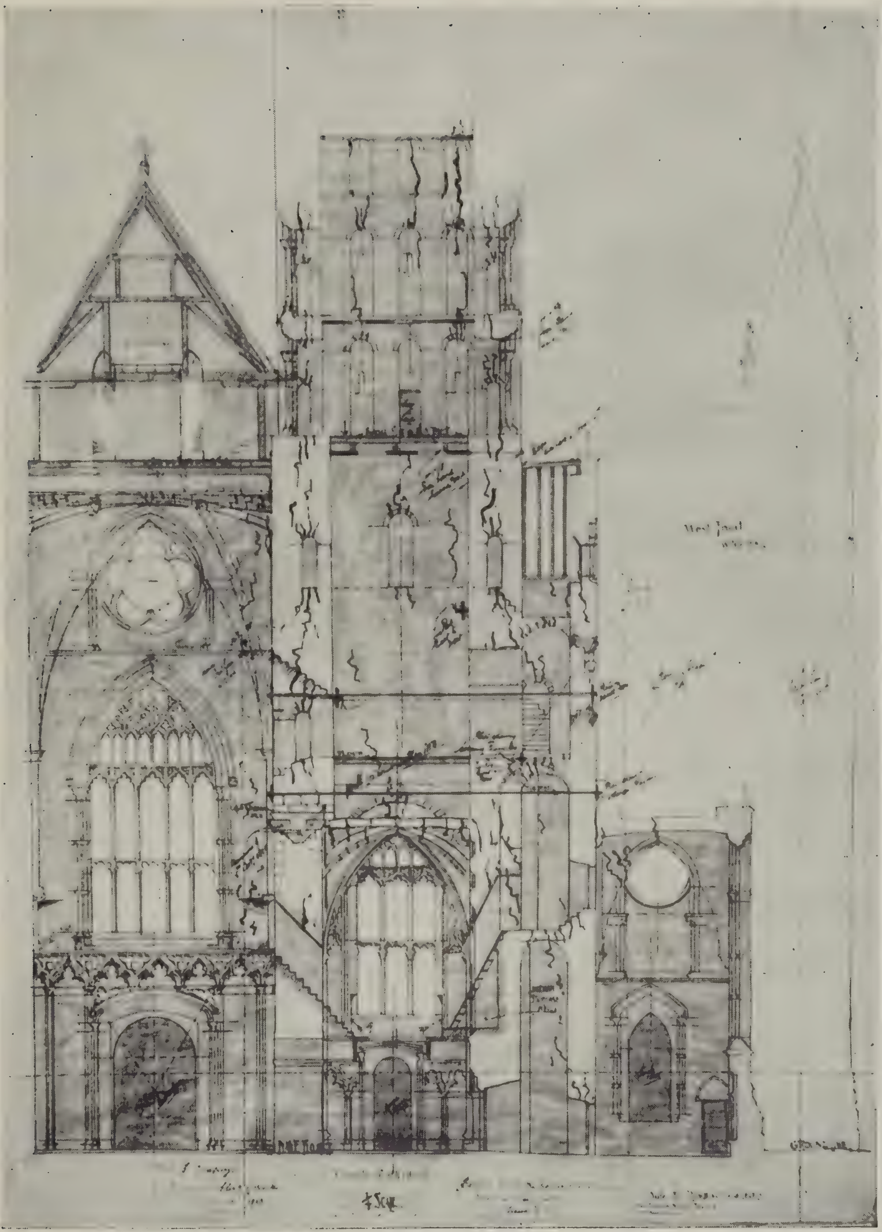
Well, there is good as well as bad grouting. Unless grouting is carried out in a proper and scientific manner, the state of the walls sooner or later will be worse than before. The proper method, is first to blow out all dust and dirt in the loose core, then thoroughly to wash out with water under pressure, to continue blowing the water in until it runs out of the surrounding places quite clean. Then while the core is still damp, you must blow the cement grout in under pressure. This pressure is varied according to requirements: 40 lbs. being the average pressure required.

If the core is not thoroughly cleaned, you simply fill the void; the cement will not adhere to the core; consequently you have added weight without adding strength to your building. (In other words it is like making concrete with dirty aggregate which is bound to end in failure.)

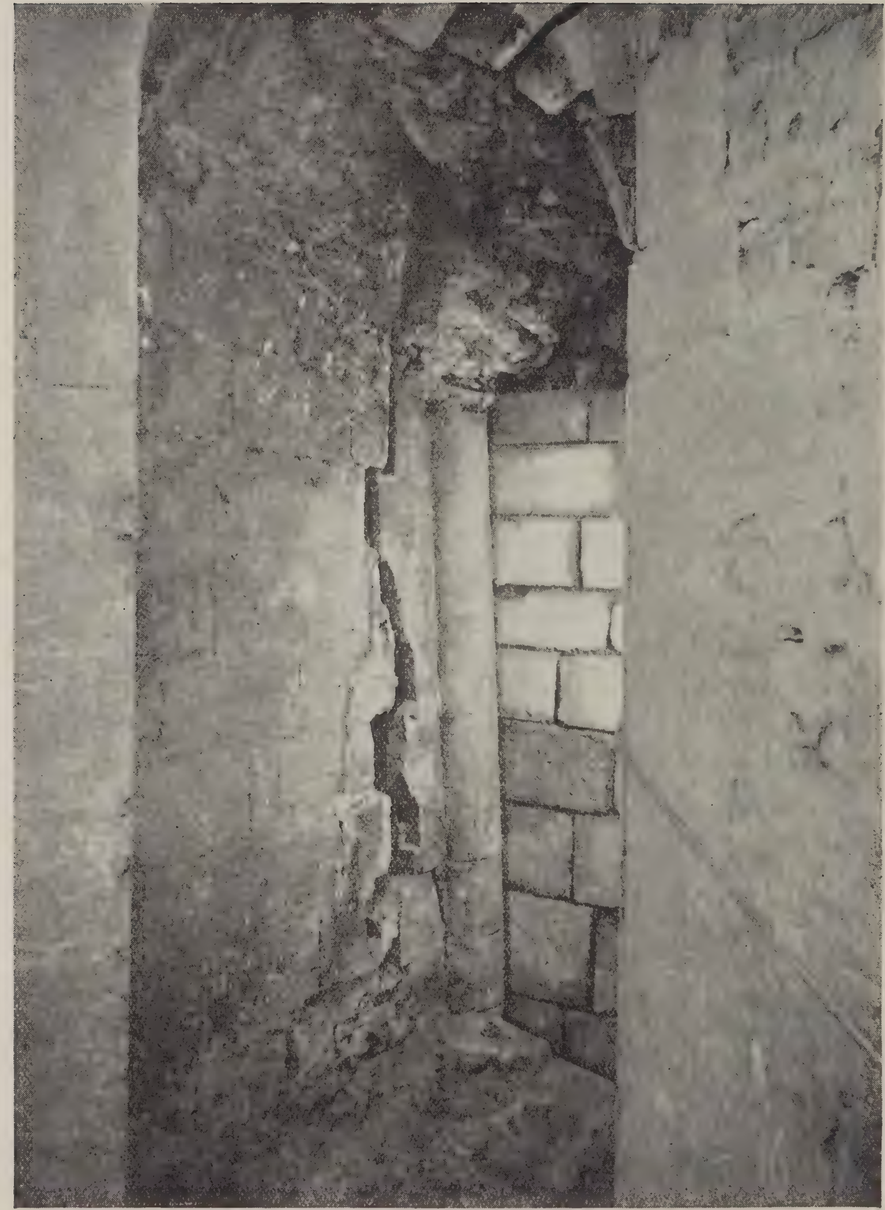
In addition to the grouting up of the cracks, we are reinforcing the masonry with Delta Bronze Cramps, an absolutely incorrodible metal, with a tensile strength of 36 tons per square inch. These cramps vary from 9 inches to 14 feet in length, and ¾ to 1 inch square. Up to October 28th inclusive we have inserted 5,406 cramps in the North West Tower, equal to 21,601 feet 4 inches or 4 miles 29 poles 2 feet 10 inches in length, and 2,961 in the Centre Tower and Transepts, equal to 9,416 feet or 1 mile 6 furlongs 10 poles 3 yard 2 feet in length, a total weight of 13 tons 4 cwts. 0 qrs. 8 lbs.

Now if you will turn to the photograph of plan No. 2, which illustrates the sectional elevation of the North West Tower, and look at the inside of the West wall to 145 feet above ground level, you will see by the zig-zag lines that the Tower was split right through from top to bottom. These cracks were equally bad on each of the other three sides. In fact, the Tower was split from floor to roof into a number of separate sections, trusting entirely to broken iron bands and bolts and broken wood-tie beams for support.

To prevent any possibility of further spreading of the Tower walls, we have (in the passages which are in the thickness of the Tower walls), constructed strong reinforced concrete beams. Six have been constructed at various heights in the North West



PLAN No. 2.
Showing cracks in N.W. Tower.



HEAD OF NORMAN STAIRCASE.

Tower. The top one of these forms the roof-plate. The four octagonal turrets are anchored to each of these beams, and each beam is well braced at the angles. It is estimated that each of these beams will stand a strain of not less than 800 tons.

It is intended to carry out this same method of bonding the four walls together in the Centre Tower. One beam is completed in the Lantern of the Tower and the reinforcement is in position ready for the concrete at the Clock Chamber Floor, 125 feet above floor level.

A similar beam has also been constructed on the Clerestory passage floors, in both North and South West Transepts.

At different periods, some of the cracks which were seen by the public and of easy access, had been filled in with pieces of stone and pointed with mortar. In two particular instances, the soffit of two arches that had collapsed at some time, some 100 feet above floor level, had been filled in with blocks of wood, and actually tightened with wooden wedges, then plastered over with mortar and lined out to imitate masonry.

In September, 1922, practically nine months after we started on these repairs, we came across the head of the Norman Staircase, which led to the top of the Tower, 45 feet above ground level (see plate opposite). On opening this out we found the wall side of this staircase split and open to an average width of four inches, to a depth as far as we were able to trace; unfortunately, we could not reveal more than seven feet down, as from this point downwards we had unbeknowingly grouted up all the rubble that the early English builders had tipped in, no doubt with the idea that this would add strength. This was certainly filled in exceedingly loose; as was proved by the enormous quantity of grout that was forced in over the section occupied by this staircase. Along the full face of the East side of the Tower up to this height, 45 feet above floor level, we forced in exactly 2,246 gallons of grout, equal to approximately 357 cubic feet, and in weight, a little over 10 tons of Cement and Sand.

One would have liked to have opened this staircase to the ground; but, as this was now grouted up, it would be almost an impossible task, so we have left the head of the staircase open for all time. This shows the newel of the staircase, which is 4½ inches in 5 feet out of perpendicular. We have left two steps down. This staircase has been lost sight of for more than 700 years.

Up to October 28th inclusive, we have forced into the walls and surrounds of the North West Tower 22,944 gallons of grout, equal to approximately 3,671 cubic feet of space, and weighing approximately 104 tons, and into the Transepts and the Centre Tower 10,372 gallons of grout, equal to approximately 1,659 cubic feet of space, and weighing approximately 47 tons. What with the grout, the constructing of the reinforced beams and re-building of the masonry in different parts, and reinforced concrete floors, we have used a total of 446 tons of cement, and 471 tons 19 cwts. of sand. To September 30th, 1925, inclusive, 2,177 new stones, equal to approximately 1,766 cubic feet of space, have been used.

This does not mean that we have increased the total weight of the building, far from it. Against this we have to calculate the hundreds of tons of debris old timbers and ironwork which we have removed from the building.

The expense to date on the North West Tower, amounts to £29,319 2s. 8d., and the Centre Tower and Transepts £11,317 8s. 0d., a total of £40,636 10s. 8d. Of this £19,182 3s. 10d. has been spent on plant and materials, and the balance of £21,454 6s. 10d. has been expended in wages. (N.B.—This was for wages and materials only up to November, 1925.)

The whole of the work has been carried out by direct labour by local workmen ; the leading men having been specially trained for the specific branch they are engaged upon.

This brings me to a point where I shall have to stop as I have already exceeded my allotted time. I am sure you will realize, that to deal with repairs of such magnitude in detail I should have to trespass on considerably more of your valuable time.

I would like to say that owing to the modern application of compressed air we are making a considerable saving in the total cost, in some cases as much as 800 per cent. over the old methods of hand labour.

All old stonework is cut out by a tool known in the foundries as Little David Chippers ; these tools are also used for cutting away all the old ironwork ; the new stonework is being dressed by the same tool. The carving is executed by specially constructed compressed air tools, capable of cutting to a minimum of 1,000th part of an inch. Air drills and saws are used for all carpentry work, a compressed air and water spray of my own invention is used for scouring the walls after grouting, and is also used for laying the dust created by the Jackhammers. By the use of this tool, the drillers are able to work in confined spaces without any ill effects from the dust. Further, compressed air is also brought into requisition for forcing water from the Corporation supply to tanks on the top of the Towers some further 200 feet up ; we thus do away with the necessity of power-driven pumps.

Before closing I would like to add my appreciation of the kindness and help that I have received from Sir Charles Nicholson, Sir Francis Fox, the Dean and Chapter and the two Committees, and from all those both at home and abroad who have liberally given us their money ; also from the loyal co-operation of all the workmen employed on these repairs. It is only by this co-operation and loyalty that this method of repairs has been brought to such a pitch of perfection ; and during the whole of the work, by the Providence of our Maker, we have been safely guarded from any serious accidents, for which we are deeply grateful.

Thanking you all present for the privilege of allowing me to give you this paper.

ROBT. S. GODFREY,

Surveyor and Clerk of Works.

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